CLAIMS

[C001] 1. An apparatus for controlling a plurality of locomotives, said locomotives being responsive to a plurality of discrete actual commands, said apparatus comprising:

a combination generator adapted for generating combinations of said discrete actual commands to yield a command combination set;

a performance calculator adapted for calculating a performance parameter set from said command combination set;

a feasible combination selector adapted for selecting a feasible combination subset from said command combination set as a function of a discrete performance setpoint, a performance tolerance, and said performance parameter set;

an objective function calculator adapted for calculating an objective function set from said feasible combination subset; and

an optimal command selector adapted for selecting an optimal command combination from said feasible combination subset corresponding to an optimum value of said objective function set.

[C002] 2. The apparatus of claim 1 wherein said combination generator is further adapted for generating all possible combinations of said discrete actual commands.

[C003] 3. The apparatus of claim 1 wherein said combination generator is further adapted for generating only combinations wherein said discrete actual commands corresponding to selected locomotives are equal.

[C004] 4. The apparatus of claim 1 wherein:

said performance calculator is further adapted for calculating total power of said plurality of locomotives;

said discrete performance setpoint is a request for a level of said total power;

said performance tolerance is a power tolerance; and

said feasible combination subset contains only said combinations of said discrete actual commands resulting in said total power within said power tolerance of said request.

[C005] 5. The apparatus of claim 1 wherein said discrete performance setpoint has a finer resolution than said discrete actual commands.

[C006] 6. The apparatus of claim 1 wherein said objective function calculator is further adapted for calculating a quantity selected from the group consisting of fuel efficiency, fuel remaining in each locomotive, engine wear, cab noise, and deviation from said discrete performance setpoint.

[C007] 7. The apparatus of claim 1 wherein said performance calculator further comprises:

an observer adapted for estimating a set of estimated state variables corresponding to said locomotives; and

a performance module adapted for calculating said performance parameter set from said command combination set and said estimated state variables,

said observer comprising:

an update module adapted for generating state update signals from measured process outputs and predicted process outputs; and

a process model adapted for propagating said estimated state variables and calculating said predicted process outputs using said state update signals and a set of measured process inputs.

[C008] 8. The apparatus of claim 7 wherein said observer is an extended Kalman filter.

[C009] 9. The apparatus of claim 7 wherein said process model comprises:

a cylinder charge estimator adapted for estimating a cylinder charge from a fuel command using a cylinder charge versus fuel command table;

a cylinder frequency calculator adapted for calculating a cylinder frequency from an engine speed measurement;

a multiplier adapted for multiplying said cylinder charge by said cylinder frequency to yield a fuel flow estimate;

an electrical power calculator adapted for calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said cylinder charge versus fuel command table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel command and said engine speed measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C010] 10. The apparatus of claim 7 wherein said process model comprises:

a fuel flow calibration module adapted for generating a fuel flow estimate from a fuel flow measurement using a fuel flow calibration table;

an electrical power calculator adapted for calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said fuel flow calibration table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel flow measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C011] 11. The apparatus of claim 7 wherein said process model comprises:

a fuel flow calculator adapted for generating a fuel flow estimate from an electrical power measurement using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said electrical power measurement,

said predicted process outputs comprising said consumed fuel volume estimate,

said measured process outputs comprising a consumed fuel volume measurement.

[C012] 12. The apparatus of claim 1 further comprising a transition control module adapted for computing an applied command combination from said discrete performance setpoint and said optimal command combination using a transition control method comprising:

ramping elements of said applied command combination toward respective elements of said optimal command combination; and

delaying said ramping of a subset of said elements of said applied command combination to minimize an adverse performance response.

[C013] 13. The apparatus of claim 12 wherein said act of delaying said ramping further comprises waiting a specified time, said specified time being a function of said optimal command combination and a previous value of said applied command combination.

[C014] 14. The apparatus of claim 12 wherein said act of delaying said ramping further comprises:

calculating a predicted performance response due to said ramping said elements of said applied command combination; and

delaying said ramping of said subset of said elements of said applied command combination until said predicted performance response satisfies a transition performance criterion.

[C015] 15. An apparatus for controlling a plurality of locomotives, said locomotives being responsive to a plurality of discrete actual commands, said apparatus comprising:

a combination generator adapted for generating combinations of said discrete actual commands to yield a command combination set;

a performance calculator adapted for calculating a performance parameter set from said command combination set;

a feasible combination selector adapted for selecting a feasible combination subset from said command combination set as a function of a discrete performance setpoint, a performance tolerance, and said performance parameter set;

an objective function calculator adapted for calculating an objective function set from said feasible combination subset; and

an optimal command selector adapted for selecting an optimal command combination from said feasible combination subset corresponding to an optimum value of said objective function set,

said performance calculator being further adapted for calculating total power of said plurality of locomotives,

said discrete performance setpoint being a request for a level of said total power,

said performance tolerance being a power tolerance,

said feasible combination subset containing only said combinations of said discrete actual commands resulting in said total power within said power tolerance of said request,

said discrete performance setpoint having a finer resolution than said discrete actual commands.

[C016] 16. The apparatus of claim 15 wherein said combination generator is further adapted for generating all possible combinations of said discrete actual commands.

[C017] 17. The apparatus of claim 15 wherein said combination generator is further adapted for generating only combinations wherein said discrete actual commands corresponding to selected locomotives are equal.

[C018] 18. The apparatus of claim 15 wherein said objective function calculator is further adapted for calculating a quantity selected from the group consisting of fuel efficiency, fuel remaining in each locomotive, engine wear, cab noise, and deviation from said discrete performance setpoint.

[C019] 19. The apparatus of claim 15 wherein said performance calculator further comprises:

an observer adapted for estimating a set of estimated state variables corresponding to said locomotives; and

a performance module adapted for calculating said performance parameter set from said command combination set and said estimated state variables,

said observer comprising:

an update module adapted for generating state update signals from measured process outputs and predicted process outputs; and

a process model adapted for propagating said estimated state variables and calculating said predicted process outputs using said state update signals and a set of measured process inputs.

[C020] 20. The apparatus of claim 19 wherein said process model comprises:

a cylinder charge estimator adapted for estimating a cylinder charge from a fuel command using a cylinder charge versus fuel command table;

a cylinder frequency calculator adapted for calculating a cylinder frequency from an engine speed measurement;

a multiplier adapted for multiplying said cylinder charge by said cylinder frequency to yield a fuel flow estimate;

an electrical power calculator adapted for calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said cylinder charge versus fuel command table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel command and said engine speed measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C021] 21. The apparatus of claim 19 wherein said process model comprises:

a fuel flow calibration module adapted for generating a fuel flow estimate from a fuel flow measurement using a fuel flow calibration table;

an electrical power calculator adapted for calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said fuel flow calibration table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel flow measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C022] 22. The apparatus of claim 19 wherein said process model comprises:

a fuel flow calculator adapted for generating a fuel flow estimate from an electrical power measurement using an electrical power versus fuel flow table; and

an integrator adapted for integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said electrical power measurement,

said predicted process outputs comprising said consumed fuel volume estimate,

said measured process outputs comprising a consumed fuel volume measurement.

[C023] 23. The apparatus of claim 15 further comprising a transition control module adapted for computing an applied command combination from said discrete performance setpoint and said optimal command combination using a transition control method comprising:

ramping elements of said applied command combination toward respective elements of said optimal command combination; and

delaying said ramping of a subset of said elements of said applied command combination to minimize an adverse performance response.

[C024] 24. The apparatus of claim 23 wherein said act of delaying said ramping further comprises waiting a specified time, said specified time being a function of said optimal command combination and a previous value of said applied command combination.

[C025] 25. The apparatus of claim 23 wherein said act of delaying said ramping further comprises:

calculating a predicted performance response due to said ramping said elements of said applied command combination; and

delaying said ramping of said subset of said elements of said applied command combination until said predicted performance response satisfies a transition performance criterion.

[C026] 26. A method for controlling a plurality of locomotives, said locomotives being responsive to a plurality of discrete actual commands, said method comprising:

generating combinations of said discrete actual commands to yield a command combination set;

calculating a performance parameter set from said command combination set;

selecting a feasible combination subset from said command combination set as a function of a discrete performance setpoint, a performance tolerance, and said performance parameter set;

calculating an objective function set from said feasible combination subset; and

selecting an optimal command combination from said feasible combination subset corresponding to an optimum value of said objective function set.

[C027] 27. The method of claim 26 wherein said act of generating combinations further comprises generating all possible combinations of said discrete actual commands.

[C028] 28. The method of claim 26 wherein said act of generating combinations further comprises generating only combinations wherein said discrete actual commands corresponding to selected locomotives are equal.

[C029] 29. The method of claim 26 wherein said act of calculating a performance parameter set further comprises calculating total power of said plurality of locomotives,

said discrete performance setpoint beinga request for a level of said total power,

said performance tolerance being a power tolerance,

said feasible combination subset containing only said combinations of said discrete actual commands resulting in said total power within said power tolerance of said request.

[C030] 30. The method of claim 26 wherein said discrete performance setpoint has a finer resolution than said discrete actual commands.

[C031] 31. The method of claim 26 wherein said act of calculating an objective function set further comprises calculating a quantity selected from the group consisting of fuel efficiency, fuel remaining in each locomotive, engine wear, cab noise, and deviation from said discrete performance setpoint.

[C032] 32. The method of claim 26 wherein said act of calculating a performance parameter set further comprises:

estimating a set of estimated state variables corresponding to said locomotives; and

calculating said performance parameter set from said command combination set and said estimated state variables,

said act of estimating a set of estimated state variables comprising:

generating state update signals from measured process outputs and predicted process outputs; and

propagating said estimated state variables and calculating said predicted process outputs using said state update signals and a set of measured process inputs.

[C033] 33. The method of claim 32 wherein said act of estimating a set of estimated state variables implements an extended Kalman filter.

[C034] 34. The method of claim 32 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

estimating a cylinder charge from a fuel command using a cylinder charge versus fuel command table;

calculating a cylinder frequency from an engine speed measurement;

multiplying said cylinder charge by said cylinder frequency to yield a fuel flow estimate;

calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said cylinder charge versus fuel command table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel command and said engine speed measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C035] 35. The method of claim 32 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

generating a fuel flow estimate from a fuel flow measurement using a fuel flow calibration table;

calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said fuel flow calibration table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel flow measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C036] 36. The method of claim 32 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

generating a fuel flow estimate from an electrical power measurement using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said electrical power measurement,

said predicted process outputs comprising said consumed fuel volume estimate,

said measured process outputs comprising a consumed fuel volume measurement.

[C037] 37. The method of claim 26 further comprising computing an applied command combination from said discrete performance setpoint and said optimal command combination using a transition control method comprising:

ramping elements of said applied command combination toward respective elements of said optimal command combination; and

delaying said ramping of a subset of said elements of said applied command combination to minimize an adverse performance response.

[C038] 38. The method of claim 37 wherein said act of delaying said ramping further comprises waiting a specified time, said specified time being a function of said optimal command combination and a previous value of said applied command combination.

[C039] 39. The method of claim 37 wherein said act of delaying said ramping further comprises:

calculating a predicted performance response due to said ramping said elements of said applied command combination; and

delaying said ramping of said subset of said elements of said applied command combination until said predicted performance response satisfies a transition performance criterion.

[C040] 40. A method for controlling a plurality of locomotives, said locomotives being responsive to a plurality of discrete actual commands, said method comprising:

generating combinations of said discrete actual commands to yield a command combination set;

calculating a performance parameter set from said command combination set;

selecting a feasible combination subset from said command combination set as a function of a discrete performance setpoint, a performance tolerance, and said performance parameter set;

calculating an objective function set from said feasible combination subset; and

selecting an optimal command combination from said feasible combination subset corresponding to an optimum value of said objective function set,

said act of calculating a performance parameter set further comprising calculating total power of said plurality of locomotives,

said discrete performance setpoint being a request for a level of said total power,

said performance tolerance being a power tolerance,

said feasible combination subset containing only said combinations of said discrete actual commands resulting in said total power within said power tolerance of said request,

said discrete performance setpoint having a finer resolution than said discrete actual commands.

[C041] 41. The method of claim 40 wherein said act of generating combinations further comprises generating all possible combinations of said discrete actual commands.

[C042] 42. The method of claim 40 wherein said act of generating combinations further comprises generating only combinations wherein said discrete actual commands corresponding to selected locomotives are equal.

[C043] 43. The method of claim 40 wherein said act of calculating an objective function set further comprises calculating a quantity selected from the group consisting of fuel efficiency, fuel remaining in each locomotive, engine wear, cab noise, and deviation from said discrete performance setpoint.

[C044] 44. The method of claim 40 wherein said act of calculating a performance parameter set further comprises:

estimating a set of estimated state variables corresponding to said locomotives; and

calculating said performance parameter set from said command combination set and said estimated state variables,

said act of estimating a set of estimated state variables comprising:

generating state update signals from measured process outputs and predicted process outputs; and

propagating said estimated state variables and calculating said predicted process outputs using said state update signals and a set of measured process inputs.

[C045] 45. The method of claim 44 wherein said act of estimating a set of estimated state variables implements an extended Kalman filter.

[C046] 46. The method of claim 44 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

estimating a cylinder charge from a fuel command using a cylinder charge versus fuel command table;

calculating a cylinder frequency from an engine speed measurement;

multiplying said cylinder charge by said cylinder frequency to yield a fuel flow estimate;

calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said cylinder charge versus fuel command table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel command and said engine speed measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C047] 47. The method of claim 44 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

generating a fuel flow estimate from a fuel flow measurement using a fuel flow calibration table;

calculating an electrical power estimate from said fuel flow estimate using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said fuel flow calibration table, elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said fuel flow measurement,

said predicted process outputs comprising said electrical power estimate and said consumed fuel volume estimate,

said measured process outputs comprising an electrical power measurement and a consumed fuel volume measurement.

[C048] 48. The method of claim 44 wherein said act of propagating said estimated state variables and calculating said predicted process outputs comprises:

generating a fuel flow estimate from an electrical power measurement using an electrical power versus fuel flow table; and

integrating said fuel flow estimate to yield a consumed fuel volume estimate,

said state variables comprising elements of said electrical power versus fuel flow table, and said consumed fuel volume estimate,

said measured process inputs comprising said electrical power measurement,

said predicted process outputs comprising said consumed fuel volume estimate,

said measured process outputs comprising a consumed fuel volume measurement.

[C049] 49. The method of claim 40 further comprising computing an applied command combination from said discrete performance setpoint and said optimal command combination using a transition control method comprising:

ramping elements of said applied command combination toward respective elements of said optimal command combination; and

delaying said ramping of a subset of said elements of said applied command combination to minimize an adverse performance response.

[C050] 50. The method of claim 49 wherein said act of delaying said ramping further comprises waiting a specified time, said specified time being a function of said optimal command combination and a previous value of said applied command combination.

[C051] 51. The method of claim 49 wherein said act of delaying said ramping further comprises:

calculating a predicted performance response due to said ramping said elements of said applied command combination; and

delaying said ramping of said subset of said elements of said applied command combination until said predicted performance response satisfies a transition performance criterion.